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LCA FOR ENERGY SYSTEMS

Life cycle inventory of energy production in ArcelorMittal steel power plant Poland S.A. in Krakow, Poland

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Abstract

Purpose The goal of this paper is to describe the life cycle inventory (LCI) approach of energy produced by ArcelorMittal Steel Power Plant Poland (AMSPPP) in Krakow, Poland. The present LCI is representative for the reference year 2005 by application of ISO 14040: 2006. The system boundaries were labeled as gate-to-gate (it covered full process chain for energy production). Background data of inputs and outputs from the steel power plant have been inventoried as follows: consumption of energy and fuels, including: power coal (domestic), natural gas, blast furnace gas and coke oven gas, emission of air pollutants, emissions of particulate, air emissions from stockpiles, wastes, internal transport, and land use.

Main feature LCI energy generation was developed mainly on the basis of following sources: site-specific measured or calculated data, life cycle assessment (LCA) study carried out by Polish Academy of Science in Kraków, AMSPPP Environmental Impact Report, Company and literature information and expert consultations. The functional unit is represented by 977 MW of generated electric and heat energies, distributed to ArcelorMittal Steel Plant processes and to the Krakow's grid. Time coverage is 2005. Operating parameters as well as air emissions associated with the power plant boilers were presented. The production data (steams: 9, 1.6, and 0.8 MPa, electric energy, degassing softening water, softening water heat, and blast furnace blow) were given. The emissions of SO_2, NO_x, CO, CH_4, HCl, dust, heavy metals (Cr, Cd, Cu, Pb, Ni, and Mn), pollution factors (BOD_5, COD) of waste water released from ash, slag, and sludge disposals were estimated. Finally, emission of CO_2 was calculated. Continuous monitoring of air pollutant emissions conducted in two emitter units related to 977 MW energy produced in AMSPPP was discussed.

Results and discussion Related to 977 MW of energy production distributed by AMSPPP, the consumption of blast furnace gas, coke oven gas, and natural gas were 1,279.7, 47,441, and 2,080 Mm^3/year, respectively. Other fuel consumption, power coal (domestic), was 315,680 Mg/year. The production data of steams: 9, 1.6, and 0.8 MPa were estimated at 3,689,640; 227,642; and 335,010 Mg, respectively. The volume of heat was about 1,529,610 GJ. Degassing softening water and softening water represented 1,066,674 and 2,124,466 m^3. Electric energy amount was on the order 441,188 MWh, and resulting value of the blast furnace blow was 3,076,606,000 m^3. Nominal powers of the power plant boilers ranged from 149 to 177 MW. Direct dust, SO_2, NO_2, and CO emissions into the air from seven boilers (Nos. 1–7) were 33, 159.9, 134, and 8 kg/h, and from boiler No. 8 (coal-only) were 17.70, 222.6, 112, and 1.11 kg/h, respectively. Total CO_2 emission was 1,802,902 Mg. Direct CO_2 emissions from burning of power coal, blast furnace gas, coke oven gas, and finally natural gas were 674,317, 1,084,797, 39,802, and 3,986 Mg, respectively. The amounts of SO_2, NO_x (expressed as NO_2 eq.) CO, CH_4, HCl and dust emissions were 3,138.1, 2,648.5, 48.1, 575.08, 117.2, and 622.1 Mg, respectively. Contents of Mg, Cr, Cd, Cu, Pb, Ni, Mn in ash were on the order of 19.4, 1.8, 60, 50, 45, and 475 mg/kg, respectively (max. values, 28.4, 2.3, 75, 68, 59, 682, respectively). COD and BOD_5 ranged 1.2 to 17 and 10.9 to 42.7 mg O_2/dm^3, respectively. Contribution of power coal stockpiles to heavy metal emissions was relatively small. The amounts of ash–sludge mixtures and carbon volatile ash during stock of power coal were 53,078.1 and 11,272 Mg,

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respectively. Data concerning pollutants into air from continuous monitoring were not included due to a limitation of the available data. The time coverage of the data collected from continuous monitoring is 2006.

Conclusions This is the first tentative study to express energy generation in industry in Poland in terms of LCA/LCI for the energy power in steel industry. The results of the study suggest that reduction of the amount of power coal leads to saving of primary resources and reduction of SO_2 emissions, decrease land occupation caused by power coal stockpiles, and increase recovery of the blast furnace gas, as well as, coke oven gas surplus. The results may help ArcelorMittal Steel Plant government make decisions in policy making. Presentation of the study in this paper is suitable for the energy production processes, as well as other industries.

Recommendations and outlook The LCI offers environmental information consisting on the list of environmental loads. The impact assessment phase aims the results from the inventory analysis to be more understandable and life cycle impact assessment will be the direction for future research. Another issue to discuss is integration of LCA and risk assessment for industrial processes.

Keywords Air emissions · Blast furnace gas · Coke oven gas · Energy generation · Life cycle inventory (LCI) · Natural gas · Poland · Power coal · Steel power plant

1 Introduction

Electricity is a major consideration in almost all of the LCA (Di et al. 2007; Curran et al. 2005). This paper describes an LCI study of energy produced by the AMSPPP in Krakow, Poland. The framework of the study was originally carried out for 2005 data because important statistics are available for this year and also because it represents the data, which are the foundation for the Environmental Impact Report of the AMSPPP, annually collected (2005) and evaluated (Mittal 2007).

Because no LCA has ever been conducted on the energy production in steel plants in Poland, this study is the first work about LCI of energy process. The LCI study was conducted according to the requirements of the International Standards ISO 14040: 2006. The paper is organized as follows: introduction is presented first. Next, the goal and scope of the study are stated. Thereafter, main features including LCI of AMSPPP installation are developed. Then, data analysis on emission results and conclusions are performed.

1.1 Introduction to AMSPPP

The energy process in AMSPPP is manufactured mainly through combustion of powdered power coal (dust), as well as blast furnace gas, coke oven gas, and natural gas fired in steam boilers. Coke oven gas and natural gas were used as a start-up, re-burning gas, and requires installation of the coke oven gas and natural gas injection burners. AMSPPP consists of four plants located in Dabrowa, Krakow, Sosnowiec, and Swietochlowice. It boasts a full production system—from pig iron to final, highly processed steel products—producing around 6.5 million tons of crude steel annually. Today, AMSPPP is the only truly global steel maker—with operations in the USA, Canada, Mexico, Trinidad, France, Germany, Czech Republic, Poland, Romania, Bosnia, Macedonia, Kazakhstan, Algeria, and South Africa (Mittal 2003).

The AMSPPP produces:

- Electric energy
- Blast to blast furnace
- Main technological steam—9 MPa/540°C
- Technological steam—1.6 MPa/400°C
- Technological steam—0.8 MPa/260°C
- Softening water for rolling mills, Blast Oxygen Furnace (BOF), and coke oven plants
- Demineralization water for continuous casting and BOF

By the end of 2005, the size of the total energy generating installation (seven boilers) had reached 977 MW and the total production of electricity was of 133,628 MWh. The process generates of steam at the rate of 1,360 tons/h (Mittal 2003). AMSPPP is powered with five (TP-230 and OP-230) 230 tons/h steam boilers and two (OPG-220) 220 tons/h steam boilers. TP-230 and OPG-22 (Nos. 1, 2, 3, 4, 6, and 7) operate with co-firing pulverized power coal and blast furnace gas. OP-230 (No. 8) is generally a coal-fired boiler, and flue gas conditioning technology is not used because a new model of the electrostatic precipitator, designed by Luigi, based on Danish technology has been implemented for this steam boiler. The average efficiency of the electrostatic precipitator is 99.3% due to implement Pentol–Vahlko flue gas conditioning technology with gaseous SO_3 injection in the stacks before the electrostatic precipitators for the removal of volatile ash. Concentration of the fly ash was decreased to values of less than 50 mg/m^3. The temperature in the boilers varies between 510 and 540°C, and the output pressure of the main technological steam is 9 MPa. The technological steams with the pressure in the range of 0.8–1.6 MPa were used, e.g., in the coke manufacturing process, or is fed to the Water Department. The combustion process is controlled by on-line measurements and visually with the help of TV monitors. The operating parameters of the AMSPPP boilers are summarized in Table 1 and air emissions from co-firing pulverized power coal and blast furnace gas boilers were estimated and listed in Table 2:

Table 1 Operating parameters of the AMSPPP boilers

Boiler number	Start [year]	Type	Data parameters		Efficiency [t/h]	Nominal Power [MW]
			pressure [MPa]	temperature [°C]		
1	1954	TP-230	9.0	510	230	157
2	1954	TP-230	9.0	510	230	157
3	1955	TP-230	9.0	510	230	157
4	1956	TP-230	9.0	510	230	157
6	1964	OPG-220	9.0	540	220	149
7	1967	OPG-220	9.0	540	220	149
8	1983	OP-230	9.0	540	230	177

2 Goal, scope, terminology, and definitions

The goals of this study were to:

- Develop an LCA technique limited to a LCI study for AMSPPP input/output data in the energy generating case study (including the electric energy, technology practice steam, blast to blast furnace, etc.) with scope to facilitate the range of emerging impact assessment methods in future studies.
- Produce national and regional LCI data suitable for the energy industry as well as other industries.
- Promote the development of LCI and/or LCA research and application in Poland.

The data used in the study are obtained from the following sources:

- Site-specific measured or calculated data (Mittal 2003).
- LCA study carried out on behalf of the AGH-University of Science and Technology's Management Department by Polish Academy of Science in Krakow (Kulczycka and Henclik 2008).
- Value based on literature information.
- AMSPPP Environmental Impact Report (Mittal 2007).
- Company internal information (data obtained from personal communication with AMSPPP Environmental Department director).
- Expert consultation.

Data represent the integral AMSPPP situation with global coverage of the power generating process. The FU is 977 MW of generated electric and heat energies delivered to ArcelorMittal Steel Plant processes and Krakow's grid. The system boundaries, which define the scope of the study appear in Fig. 1. It covers all operations required for energy production in AMSPPP from upstream raw materials (i.e., the gate) to finished product-energy ready to be shipped from the power plant (i.e., gate). Raw fuels mining and means of external transportation of raw coal, crude oil and natural gas, manufacture of downstream products, their use, end of life were not included. Internal transport (band conveyors of 500 m) was included and land use of around 93,055 m^2 was taken into account. The internal consumption of electricity is covered by properly produced electric energy. The importation of electricity is necessary only in cases of an operational stop. Production data of main energy carriers is given in Table 4. The power plant operates 365 days a year and 24 h each day.

2.1 LCI of AMSPPP

According to AMSPPP Environmental Impact Report (Mittal 2007), the consumption of natural gas, hard coal, blast furnace gas, and coke oven gas of AMSPPP in 2005 is presented in Table 3. Power coal (domestic) and blast furnace gas have been dominant portion in the fuel consumption by AMSPPP.

Flue gas cleaning and purification process consists of the electrostatic precipitators of Polish technologies (ELWO and OPAM) with the capacity of 380,000 and 290,000 Nm^3/h, respectively, and one electrostatic precipitator based on Danish technology (Lurgi installation produced by SMS) with the capacity of 300,000 Nm^3/h. Demineralized water station is based on ion exchange technology. Regeneration of ion exchanger is carried out with HCl and NaOH (see LCI materials input data summarized in Table 4).

Table 2 Air emissions from eight boilers in power plant (kg/h)

Boilers	Dust	SO_2	NO_2	CO
Co-firing pulverized power coal and blast furnace gas boilers	33.00	159.90	134.00	8.00
Coal-fired boiler	17.70	222.6	112	1.11

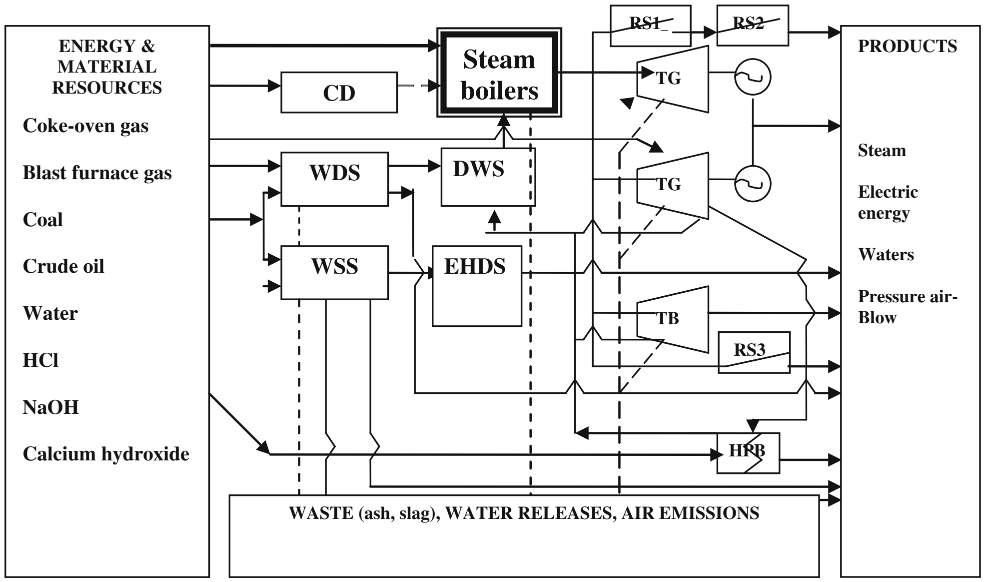

Fig. 1 System boundary of AMSPPP generation process—different processes investigated for the energy production chain of power plant installed in ArcelorMittal Steel Plant. *CD* coal deposit (yard)—input: coal, output, conveyor belt, *WDS* water demineralizing station—input: water, HCl, NaOH, output: demineralizing water, *DWS* degassing of the water supply—input: condensation water from turbogenerators, *WSS* water softening station—input: water, output: softening water, *EHDS* evaporator & heat network degassing station installation—input: degassing water, output: degassing softening water, *TG* turbogenerator—input: turbine oil, output *U*=6 KV, *RS1* reducing station nr 1—output: steam 3 MPa, *RS2* reducing station nr 2—output: steam 1.6 MPa/400°C, *RS3* reducing station nr 3—output: 0.8 MPa/240°C, *TB* turbo blower—output: blow to blast furnace, *HPB* heat power blanks—output: Steel Plant and Krakow city heating, steam boilers—input: coal from CD, blast furnace gas, coke oven gas, output: steam 9 MPa

CO_2 emissions meet the emission credits for AMSPPP. Monitoring and criteria standards for CO_2 emissions have been stated in Małopolska Provincial Office in Krakow Decision dated of 11 April 2006 (Decyzja Urzędu Wojewódzkiego-ŚR.III.JD .6610-16-1-05/06 2006). This decision covered also legal emission limits for the maximum CO_2 emissions in 2005 (Journal of Laws 2005a). In AMSPPP are eight sources of emissions, which were listed as follows: (1) four steam boilers of Russian technology (TP-230)—gas and dust were major emissions which result from the coal, coke oven gas and blast furnace gas burning, (2) two steam boilers of Polish technology (OPG-220)—gas and dust were major emissions which result from the coal, coke oven gas and blast furnace gas burning; (3) one steam boiler of Polish technology (OP-230)—gas and dust were major emissions which result from the coal combustion, (4) power coal stockpiles—fugitive source of particulate air emission (Mittal 2007). After the burning of fuels (powdered coal as well as blast furnace gas were major sources of emissions, coke oven gas—minority source of emissions, and natural gas— micro source of emissions) most of the carbon is released as CO_2, some are released as CO, and the rest is retained in the ashes and slug. CO_2 emissions measurements were performed during burning of the gas—coal powdered (dust) mix in the steam boilers.

Table 3 Consumption of natural gas, power coal, blast furnace gas and coke oven gas used for energy production in AMSPPP (2005)

Fuel	Amount	Unit
Natural gas	2,080	Mm^3
Power coal (domestic)	315,680	Mm^3
Blast furnace gas	1,279,700	Mm^3
Coke oven gas	47,441	Mm^3

3 LCI methodology

An LCI requires a lot of data (Finnveden et al. 2009). The complete inventory was integrated by 49 main environmental loads (inputs, outputs): energy and raw materials consumed, wastes produced, and emissions to air, water, and soil. A full publication of the inventory data is documented in Kulczycka and Henclik (2008). In this case study, the system evaluated does not include anything upstream from the steel production. Main properties of the energy carriers used in AMSPPP, as well as CO_2 emissions associated with fuels for AMSPPP are shown in Table 5.

4 Air pollutants

4.1 CO_2

CO_2 emission was estimated on the following formula according to European Commission 2004/156/WE Decision

Table 4 Life Cycle Inventory for AMSPPP generation process (2005). Flows are representative for the production of 977 MW electric and heat energies

Flows	Amount	Units
Input		
Energy and fuels		
Power coal	313,680	Mg
Blast furnace gas	1,279,699.80	Mg
Coke oven gas	47,440.80	Mg
Natural gas	2,080.20	Mg
Electric energy	133,628	MWh
Materials		
Industrial water	12,384,404	m^3
Drinking water	30 205	m^3
Calcium hydroxide	284.2	Mg
Kotamina[a]	8.75	Mg
Sodium phosphate	12.4	Mg
S	100	Mg
HCl	215	Mg
NaOH	219	Mg
Output		
Production data		
Steam 9 MPa	3,689,640	Mg
Steam 1.6 MPa	227,642	Mg
Steam 0.8 MPa	335,010	Mg
Electric energy	441,188	MWh
Blast furnace blow	3,076,606	$1000{*}m^3$
Degassing softening water	1,066,674	m^3
Softening water	2,124,466	m^3
Heat	1,529,610	GJ
Emission data		
SO2	3,138.1	Mg
NO2	2,648.5	Mg
Dust	622.1	Mg
Cr	10.4	kg
Cd	1.0	kg
Cu	21.3	kg
Pb	22.8	kg
Ni	19.6	kg
Mn	274.0	kg
CO	48.1	Mg
CH_4	575.08	Mg
HCl	117.2	Mg
Other wastes		
Used water	33,16958	m^3
Sludge	10.0	Mg
Other oils (gear lubricant, etc.)	15.24	Mg
Cables	11.768	Mg
Municipal solid waste—MSW	102.0	Mg

[a] Kotamina is a modern anticorrosive and antifouling formulation which has been based on thermally stable alkylamines. The use of amine in that formulation reduces the corrosive attack of water and steam (patented by Institute of Heavy Organic Synthesis "Blachowni"a, Kedzierzyn-Kozle, Poland)

pursuant to Directive 2003/87/EC of the European Parliament and given in the Council Decision on 18 July 2007 (Official Journal of the European Union 2007):

$$CO_2 \text{ emission} = \text{activity data} \times \text{emission factor} \times \text{oxidation (conversion) factor} \quad (1)$$

Activity data were based on fuel consumption. The quality of fuel was expressed in terms of energy content as TJ (Commission Decision 2007). Under the European Community program establishing a scheme for greenhouse gas emission allowance trading, Polish Government directive has established a scheme for greenhouse gas emission credits for AMSPPP covering the year 2005. The guidelines laid down in that directive determined the individual permitted emission limit values. For example if CO_2 emissions from unit 1 were lower than the given emissions limit, the emissions credit (allowance) have to be applied to the other units at AMSPPP. According to the amount of 977 MW energy production in AMSPPP, these 977 MW of delivered energy produces approx. 674,317 Mg CO_2 emitted by power coal burning, 1,084,797 Mg CO_2 emitted by blast furnace gas burning, 39,802 Mg CO_2 emitted by coke oven gas burning and, finally, 3,986 Mg CO_2 emitted by natural gas burning (see Table 5).

Regulation of the Council of Ministers on the adoption of a National Allocation Plan for emissions provided for the creation of carbon dioxide emission limits for the years 2005–2007 (Journal of Laws 2005b). In accordance with this legislation Annual Report of the CO_2 emissions has been verified by Małopolska Provincial Office Inspector of Environment (local Environmental authority). In each individual case, the permitted CO_2 emissions depend on the nature of installations.

The carbon emission factor depends highly on the heat capacity of carbon in the fuel. Carbon oxidation factor is another indicator for CO_2 emissions characteristics of fuel. In fact, it is also related to the combustion equipments, technology, and operation conditions.

Under Appendix 2 of the Ministry of Environment Regulation of 12 January 2006 on the method for monitoring the size of emissions of substances covered by the emission trading system (Journal of Laws 2006), the energy content of the fuel was calculated on the basis of the amount of fuel consumption and fuel calorific value, as expressed in Eq. (2):

$$E_{(ECF)} = M_{ACF} \times Q_{FCV} \quad (2)$$

where:

$E_{(ECF)}$ Energy content of the fuel [TJ]
M_{ACF} Amount of fuel consumption [Mg]
Q_{FCV} Fuel calorific value [TJ/Mg]

Table 5 Main properties of the energy carriers used in AMSPPP

Fuels	Power coal	Blast furnace gas	Coke oven gas	Natural gas
Amount of fuel consumption (Mg or 1000 m^3)	313,680	1,279,699.80	47,440.80	2,080.20
Energy content (TJ)	7,367.97	4,159.02	821.67	73.58
Heating value	21.963 kJ/kg	3.246 kJ/Nm^3	16.874 kJ/Nm^3	36.123 kJ/Nm^3
Carbon emission factor (Mg CO_2/TJ)	91.52	260.83	48.44	54.17
Carbon oxidation factor (Mg CO_2/TJ)	1	1	1	1
CO_2 emissions (Mg CO_2)	674,317	1,084,797	39,802	3,986
Total CO_2 emissions (Mg CO_2)	1,802,902			

The calculated values of energy contents are summarized in Table 5.

4.2 SO_2

Sulfur is one of the common harmful elements in coal (Di et al. 2007). SO_2 emission results first of all from the presence of sulfur in the fuels (Uliasz-Bochenczyk and Mokrzycki 2007). In the case of the AMSPPP plant, SO_2 produced from coal combustion was estimated based on their sulfur content and SO_2 of coke oven gas combustion was estimated based on H_2S content in coke oven gas. According to (Mittal 2007), average sulfur content of coal is generally low (less than 0.7%), and may result in SO_2 emissions of about 159.9 kg/h. The average ratio of SO_2 emissions from power coal combustion to the total SO_2 emissions released from the fuels combustion was 95%. H_2S content in the coke oven gas was 0.5 g/Nm^3. At lower coal sulfur content, the desulfurization technology is not needed.

SO_2 emission limits from all steam boilers was 5200 Mg/year, while for coal-fired steam boiler (OP-230) was 2,350 mg/m_{ref}^3 (Mittal 2007).

$$\text{emission standard requirements}: T_{\text{ref}} = 273\text{K}, \text{p}_{\text{ref}} = 101,3\,\text{kPa at } 6\%\ O_2$$

4.3 NO_x

NO_x formation in coal fuels-fired power stations occurs through complex chemical reactions. NO_x are formed from the oxidation of nitrogen contained within the fuels and from the combustion air (Di et al. 2007); NO_x emissions from fossil fuels power station known as fuel-NO_x and thermal-NO_x, respectively (Air pollution control 1995).

NO_x (expessed as NO_2 eq.) emission limits from all steam boilers was 3,600 Mg/year, while for coal-fired steam boiler (OP-230) was 600 mg/m_{ref}^3 (Mittal 2007).

$$\text{Emission standard requirements}: T_{\text{ref}} = 273\,\text{K}, p_{\text{ref}} = 101.3\,\text{kPa at } 6\%\ O_2$$

4.4 Dust

Dust emissions limit from all steam boilers was 825 Mg/year, while for coal-fired steam boiler (OP-230), it was 350 mg/m_{ref}^3 (Mittal 2007).

$$\text{Emission standard requirements}: T_{\text{ref}} = 273\,\text{K}, p_{\text{ref}} = 101,3\,\text{kPa determined for dry gas by } O_2 \text{ at } 6\%$$

4.5 Heavy metals

In the process of fuels combustion, some heavy metal elements in fuels would be transferred into ash, and the rest would be released into exhaust gas from boilers (Di et al. 2007). Content of heavy metals in ash emitted from AMSPPP (Mittal 2007) are listed in Table 6.

Continuous monitoring of air pollutant emissions is conducted in two emitter units. Dust-laden gas from the boilers (No. 1–4) and from the boilers (No. 6–8) is passed via electrostatic precipitators to the two emitter stacks. The emitter stack chambers height and outlet diameter are generally about 200 and 6 m, respectively. Continuous

Table 6 Content of heavy metals in ash emitted from AMSPPP (mg/kg)

Content	Cr	Cd	Cu	Pb	Ni	Mn
Average	19.4	1.8	60	50	45	475
Maximal	28.4	2.3	75	68	59	682

monitoring is designed to order to comply with the BAT technique under Section 1.14.1 of the IPPC Reference Document on the General Principles of Monitoring (BAT 2005). All combustion processes in AMSPPP must according to the present legislation meet the legislative emission limits: Journal of Laws (2005a). Pollutants into air from continuous monitoring were not included due to a limitation of the available data.

After 2005, combustion modifications for the power station in AMSPPP have been developed. In the case of NO_x control emissions, combustion modifications for power boilers (Nos. 1–4 and 6–7) included the operational optimization (low excess air), and low NO_x burners. In the case of particulate control emissions, combustion modifications for power boilers (Nos. 1, 2, and 4) were based on advanced electrostatic precipitators, gas conditioning system for all power boilers, and coal burning with low content of un combustible matters (Mittal 2007).

5 Water pollutants and particulate air pollution

The AMSPPP Environmental Impact Report (Mittal 2007) recognizes the power coal stockpiles as only one fugitive source of particulate air emission in the considered installation. The annual emission of stored coal dust is largely determined by the annual amount of the total delivery coal estimated at 300,000 Mg/year, and average coal quantity stored during the year estimated at 17,000 Mg. Dust emission factor during the coal loading and unloading taken from EPA, cited in Mittal (2007), reached 0.055 g/Mg, while fugitive particulate emission factor caused by wind erosion from coal stockpile obtained from Cowherd, cited in Mittal (2007), was expressed as about 41 g/Mg of average coal mass loaded during annual time of dumper. In Poland, general wind direction of wind is from the west. As calculated, the particulate (dust) air pollution by the utilization of emission factor data presented above the hard coal stockpiles generated 0.707 Mg dust/year (0.0807 kg/h). Heavy metal emissions of hard coal stockpiles were usually negligible. The ash–sludge mixtures and carbon volatile ash was 53,078.1 and 11,272 Mg, respectively.

Waste water (water after draining system) from Sewage Treatment Plant and waste water released from ash, slag, and sludge disposals (see Fig. 2) within the levels established by applicable Polish Water Laws and Regulations, as presented in Table 7, are carried out to the Vistula river.

6 Discussion

LCI studies regarding energy productions can be found in Peiu (2007); Di et al. (2007); Dubreuil (2001); Coltro et al. (2003), and Sate et al. (2005). Finnveden et al. (2005), referring to the study of Weidema et al. (1999) discuss the long-term, base-load marginal for the European electricity market. They state that the trend for electricity use in Europe is increasing and that the marginal technology thus would be the most preferred technology. Their conclusion is that hard coal is the EU marginal power source. Poland is the largest hard coal producer in the European Union, producing annually almost 88 million tons of this raw mineral. The production of Polish coal constitutes more than half of the production of the European Union and in the case of steam coal it is 59% and in the case of coking coal about 39%.

Coal is a predominant fuel in Poland for generation of electric energy; 95% of energy generated comes from coal (in which about 55% of the energy is generated from hard coal and about 40% from brown coal (Zych 2008)). The option of nuclear energy introduced into Polish national energy sector is considered in the future. Potential of the new investments was complemented by adding renewable energy source, resulting as a complete technological outlook of the whole energy sector. In Poland, the number of professional combined heat and power plants (over 50) is greater than the number of professional power plants (over 20), but the power production rate is significantly smaller there (about 21 TWh in 2006; Uliasz-Bochenczyk and Mokrzycki 2007).

In this study, the energy process is based on the power coal (dust), as well as blast furnace gas, coke oven gas, and natural gas fired in the steam boilers of the AMSPPP in Krakow, Poland.

As stated above, average sulfur content of power coal used in AMSPPP is less than 0.7%. According to related researches described in Di et al. (2007), the sulfur content of raw coal was 1.05% in China. The sulfur contents of coals used in Germany and Japan are generally low (less than 1.2%). Compared with the US coals, the relative values of sulfur, ash, and trace elements concentrations differ from those in coals used in Germany and Japan (Air pollution 1995).

Treatment of stack gases in AMSPPP was approximately equal with developed countries, such as Japan. The average efficiency of AMSPPP's electrostatic precipitator was 99.3% in 2005, while average precipitating efficiency of precipitators in Japan's thermal power plants was as high as 99.5%. In China's thermal power plants, the average precipitating efficiency of precipitators was about 97% in 2002 (Di et al. 2007).

In the AMSPPP's strategy of the energy production in the future, implementation of modern gas boilers using blast furnace gas, instead the power coal, is considered but this solution is technically premature to be implemented and is very costly. As mentioned above, at lower coal sulfur

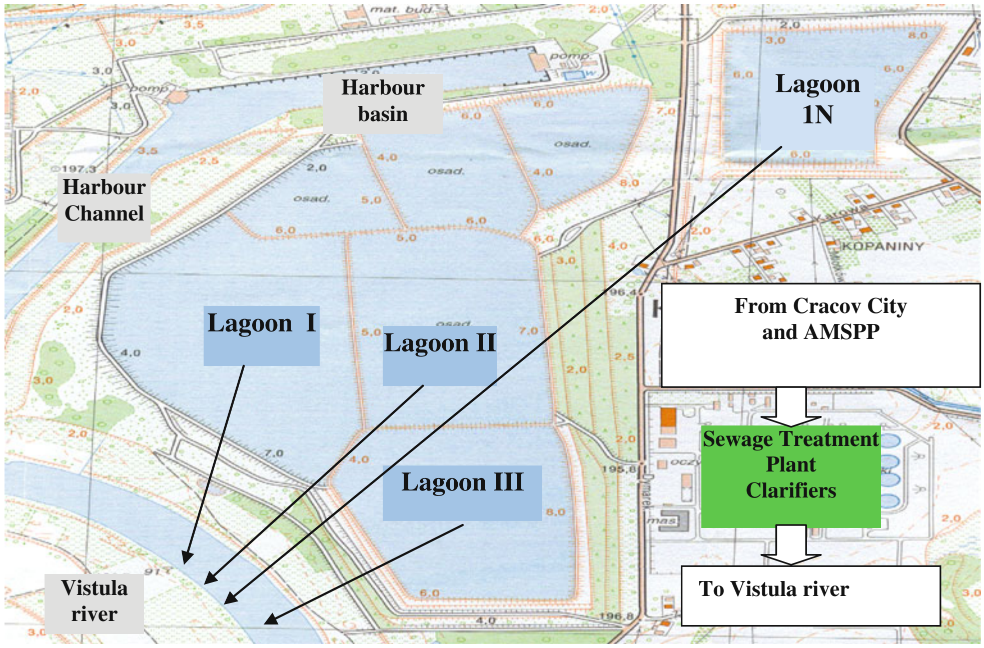

Fig. 2 Plan view of the ArcelorMittal Steel Poland sludge disposal (*Lagoon 1N*), and ash, slag disposals (*Lagoons I*, *II*, and *III*)

content, the desulfurization technology is not needed. Flue gases are generally discharged to the base of chimneys at minimum temperatures of 180°C. The chimney must also be constructed so that both the gas flue and the structural shell are suited to the particular duty, for example with regard to chemical properties and temperature of the gases and resistance to abrasion. The amount of blast furnace gas strongly depends on the quality of pig iron production process. Blast furnace gas is considered as a by-product, and the reason for the use of this medium for energy production processes is a way of utilizing it. Requirement for a higher amount of pig iron production generally results in higher CO_2 and CH_4 emissions. Generally, surplus of the process blast furnace gas not burned in AMSPPP is transferred either to other steel facilities (blast furnace stoves and soaking pits of hot rolling mills) or to flare stacks and combusted. Air emissions due to flaring are usually negligible compared to the energy process stage air emissions. Moreover, surplus of the process coke oven gas is transferred either to heating channels of the coke oven batteries, or, like blast furnace gas, to soaking pits of hot rolling mills. A number of alternative fuel mix combinations are possible, with the seasonal change in power coal demand. During winter time, higher power coal demand is caused by higher production of technological steam, used for the central heating supply of Krakow. The relatively high deviation content of heavy metals in ash emitted from AMSPPP (see Table 6) are due to different shares of power coal, extracted generally from two coal mines.

7 Conclusions

The LCI of energy production in AMSPPP is focused on the production and operation results in 2005, as defined in the goal and scope. This is the first tentative study to express energy generation in industry in Poland in terms of LCA/LCI for the energy power in steel industry. The production of 977 MW electric and heat energies distributed to energy users (ArcelorMittal Steel Plant processes and Krakow's grid) in 2005 was the FU selected. Presentation of the study in this paper is suitable for the energy production processes, as well as other industries. Amount of blast furnace gas strongly depends on the quantity of pig iron production process. Requirements for a higher amount of pig iron production generally results in higher CO_2 emissions. However, it is expected that reduction of power coal share burned in the power plant results from increasing

Table 7 Monitoring and limit levels of waste water released from ash, slag and sludge carried out to the Vistula river

Pollution factor	Unit	Waste water released from ash, slag and sludge disposals		Limited value standard levels
		Min	Max	
BOD_5	mg O_2/dm^3	1.2	17	25
COD	mg O_2/dm^3	10.9	42.7	125.0

amount of blast furnace gas combusted in the power plant, decreasing the cost of energy in power station, and reducing the total amount of SO_2 in the flue gas.

The results of the study were the basis for the decision-making process. It helped ArcelorMittal Steel Plant government to solve environmental and technical aspects, because reduction of the amount of power coal leads to saving of primary resources and reduction of SO_2 emissions, decrease in land occupation caused by power coal stockpiles, and increased recovery of the blast furnace gas, as well as, coke oven gas surplus (considered as co-products, no waste). Moreover, these results move the LCI study on the energy mix production one step forward.

8 Recommendations and outlook

The research described in this paper can also serve as the basis for future work. The potential direction for future research is to integrate LCA and risk assessment for industrial processes. A complementary paper will be produced and will be submitted to this journal in which life cycle impact assessment will be discussed.

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